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CENTRE NUMBER		CANDIDATE NUMBER	

PHYSICS **9702/41**

Paper 4 A Level Structured Questions **May/June 2018**

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.
DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.
You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

This document consists of **23** printed pages and **1** blank page.

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Data

speed of light in free space	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
	$(\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
unified atomic mass unit	$1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall	$g = 9.81\,\mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho g h$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega\sqrt{(x_0{}^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy of charged capacitor	$W = \frac{1}{2}QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

Answer **all** the questions in the spaces provided.

1 **(a)** State Newton's law of gravitation.

Force on each point mass is proportional to product of masses and inversely proportional to square of separation.

....[2]

(b) A distant star is orbited by several planets. Each planet has a circular orbit with a different radius.

(i) Each planet orbits at constant speed.
Explain whether the planets are in equilibrium.

Since it is travelling at constant speed with change in direction, velocity is changing hence it is not in equilibrium

....[1]

(ii) The radius of the orbit of a planet is R and the orbital period is T.

Data for some of the planets are given in Fig. 1.1.

planet	R/m	T^2/s^2
c	9.6×10^{10}	2.5×10^{11}
e	4.0×10^{11}	1.8×10^{13}
g	2.1×10^{12}	2.6×10^{15}

Fig. 1.1

The relationship between R and T is given by the expression

$$R^3 = kT^2.$$

1. Show that the constant *k* is given by the expression

$$k = \frac{GM}{4\pi^2}$$

where *G* is the gravitational constant and *M* is the mass of the star.

Gravitational force = centripetal force

$$\frac{GM\cancel{m}}{R^2} = \frac{\cancel{m}v^2}{R}$$

$$\boxed{v = \omega \times r \qquad v = \frac{2\pi R}{T}}$$

$$\frac{GM}{R} = v^2$$

$$\frac{GM}{R} = \frac{4\pi^2R^2}{T^2} \longrightarrow R^3 = \frac{GMT^2}{4\pi^2}$$

$$R^3 = kT^2$$

[3]

2. Use data from Fig. 1.1 for the three planets and the expression for *k* to calculate the mass *M* of the star.

$$(9.6\times10^{10})^3 = k(2.5\times10^{11})^2$$

$$k = 3.54\times10^{21}$$

Since $k = \frac{GM}{4\pi^2}$, $\frac{3.54\times10^{21}\times4\pi^2}{6.67\times10^{-11}} = M$

M = 2.1×10^{33} kg [3]

[Total: 9]

2 A metal plate is made to vibrate vertically by means of an oscillator, as shown in Fig. 2.1.

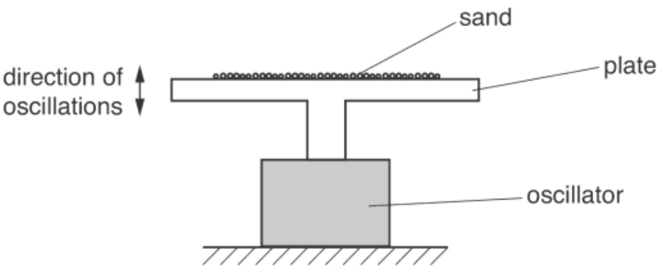
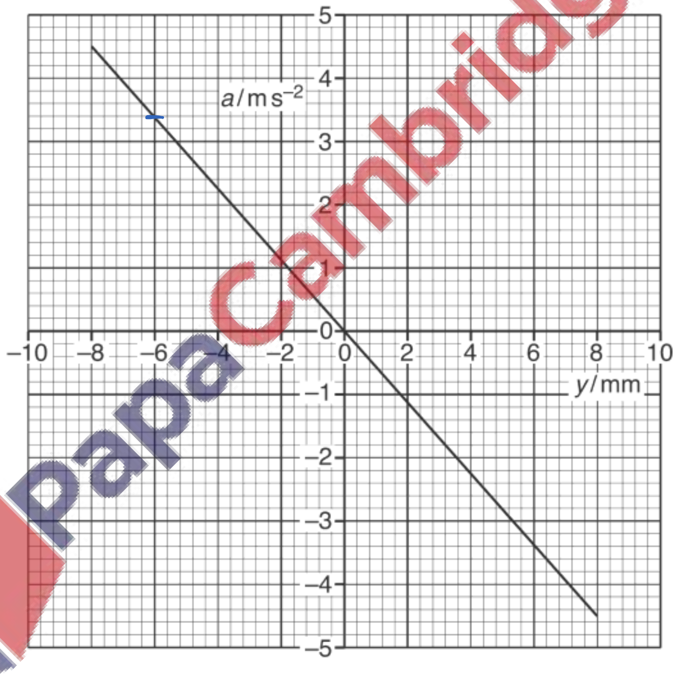


Fig. 2.1

Some sand is sprinkled on to the plate.

The variation with displacement y of the acceleration a of the sand on the plate is shown in Fig. 2.2.



constant change in acceleration

$a=-\omega^2 x$

Fig. 2.2

(a) **(i)** Use Fig. 2.2 to show how it can be deduced that the sand is undergoing simple harmonic motion.

Straight line through origin suggests acceleration is proportional to displacement and negative slope means acceleration and displacement are in opposite directions.

[2]

(ii) Calculate the frequency of oscillation of the sand.

$\boxed{\omega = 2\pi f}$

$$a = -\omega^2 x$$
$$3.4 = -\omega^2\left(\frac{-6}{1000}\right)$$
$$\omega = 23.80476$$
$$f = \frac{23.80476}{2\pi}$$

frequency = 3.8 Hz [2]

sand travels greater distance

(b) The amplitude of oscillation of the plate is gradually increased beyond 8 mm. The frequency is constant.

At one amplitude, the sand is seen to lose contact with the plate.

For the plate when the sand first loses contact with the plate, $a = -9.81\ \text{ms}^{-2}$

(i) state the position of the plate,

maximum displacement upwards [1]

(ii) calculate the amplitude of oscillation.

$$a = -(2\pi f)^2 x$$
$$-9.81 = -(2\pi \times 3.8)^2 \times x$$

The greater the displacement, the greater the acceleration

amplitude = 17 mm [3]

[Total: 8]

3 **(a)** **(i)** State what is meant by the *internal energy* of a system.

Sum of kinetic and potential energies of molecules in random motion

[2]

(ii) Explain why, for an ideal gas, the change in internal energy is directly proportional to the change in thermodynamic temperature of the gas.

Internal energy for an ideal gas is only total kinetic energy because of negligible intermolecular forces so no potential energy. Mean transitional kinetic energy of molecules is directly proportional to thermodynamic temperature.

[3]

(b) A cylinder of volume $1.8 \times 10^4\,\text{cm}^3$ contains helium gas at pressure $6.4 \times 10^6\,\text{Pa}$ and temperature 25 °C.
Helium gas may be considered to be an ideal gas consisting of single atoms.

NOT moles

Calculate the number of helium atoms in the cylinder.

$$6.4 \times 10^6 \times \left(\frac{1.8 \times 10^4}{(100)^3}\right) = n \times 8.314 \times (25 + 273)$$

$$n = 46.5 \text{ moles}$$

$$1 \text{ mole} = 6.02 \times 10^{23}$$

$$46.5 \times 6.02 \times 10^{23}$$

number = 2.8×10^{25} [3]

[Total: 8]

4 Piezo-electric transducers are used for the generation of ultrasonic waves.

(a) State one other use, apart from in ultrasound, of piezo-electric transducers.

Microphone

....[1]

(b) Explain the main principles behind the **use** of ultrasound to obtain diagnostic information about internal body structures.

Ultrasound pulses are transmitted into the structure and reflected pulses from boundary are received by transmitter. This data is then analysed and a graph is plotted on oscilloscope. Gel is used on the skin to minimize reflection and the intensity of reflected pulse tells us about the nature of the boundary. Time delay between transmitted and reflected pulses determines the depth of boundary.

....[6]

[Total: 7]

5 A geostationary satellite orbits the Earth with a period of 24 hours.

(a) State

(i) the direction of the orbit about the Earth,

west to east ....[1]

(ii) the position of the satellite relative to the Earth's surface,

above the Equator ....[1]

(iii) a typical frequency for communication between the satellite and Earth.

frequency = 2×10^{9} .... Hz [1]

(b) A signal transmitted from Earth to a satellite has an initial power of 3.0 kW. The signal power received by the satellite is attenuated by 195 dB.

received signal is greater than the transmitted signal

(i) Calculate the signal power received by the satellite.

$$\text{no. of dB} = 10\log\left(\frac{P_2}{P_1}\right)$$

$$-195 = 10\log\left(\frac{P_2}{3000}\right)$$

received

transmitted

power = 9.49×10^{-17} .... W [3]

(ii) By reference to your answer in **(i)**, explain why different frequencies are used for the up-link and the down-link in communication with the satellite.

Uplink has smaller intensity than down link so different frequency is used to prevent down link from swamping up link.

....................[2]

[Total: 8]

6 **(a)** State what is meant by *electric field strength*.

Force per unit charge

....[1]

(b) An isolated metal sphere A of radius 26 cm is positively charged. Sphere A is shown in Fig. 6.1.

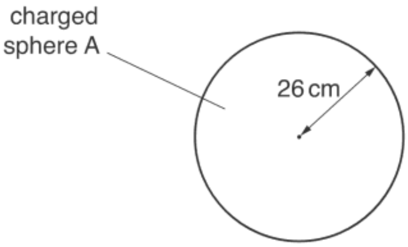


Fig. 6.1

Electrical breakdown (a spark) occurs when the electric field strength at the surface of the sphere exceeds $2.0 \times 10^4\,\text{V m}^{-1}$.

Calculate the maximum charge Q that can be stored on the sphere.

$$EFS = \frac{kQ}{r^2} \quad \text{where } k = \frac{1}{4\pi\varepsilon_0}$$

$$2\times10^4 = \frac{Q}{4\pi\varepsilon_0 \times (0.26)^2}$$

Q = 1.5×10^{-7} C [2]

(c) A second isolated metal sphere B, also with charge $+Q$, has a radius of 52 cm. $r \uparrow 2$

Calculate the additional charge, in terms of Q, that may be stored on this sphere before electrical breakdown occurs.

$$EFS = \frac{kQ}{r^2}$$

$$2\times10^4 = \frac{Q}{4\pi\varepsilon_0 \times (0.52)^2}$$

total charge = 6.014×10^{-7} C which is $4Q$ so additional charge is $4Q - Q$

additional charge = $3Q$ [2]

[Total: 5]

7 **(a)** Explain what is meant by the *capacitance* of a parallel plate capacitor.

Charge / potential where charge is of one plate and potential is potential difference between charged plates

[3]

(b) A parallel plate capacitor C is connected into the circuit shown in Fig. 7.1.

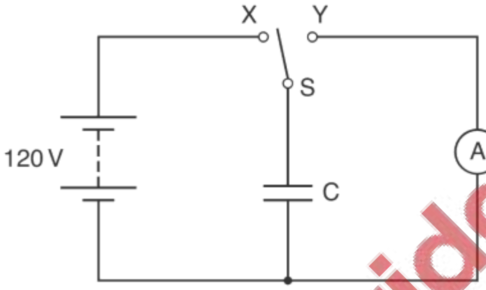


Fig. 7.1

When switch S is at position X, the battery of electromotive force 120 V and negligible internal resistance is connected to capacitor C.
When switch S is at position Y, the capacitor C is discharged through the sensitive ammeter.

The switch vibrates so that it is first in position X, then moves to position Y and then back to position X fifty times each second.

The current recorded on the ammeter is 4.5 μA. 4.5×10^{-6} A

Determine

(i) the charge, in coulomb, passing through the ammeter in 1.0 s,

Charge = current × time

$= 4.5 \times 10^{-6} \times 1$

charge = 4.5×10^{-6} C [1]

(ii) the charge on one plate of the capacitor, each time that it is charged,

In 1·0s, $4 \cdot 5 \times 10^{-6}$ C of charge flows through ammeter and the switch vibrates 50 times in 1·0s from charging to discharging. This means a total of charge $4 \cdot 5 \times 10^{-6}$ C in 50 vibrations so the first time it makes contact with X, it charges to $\frac{4 \cdot 5 \times 10^{-6}}{50}$

charge = ... 9×10^{-8} ...... C [1]

(iii) the capacitance of capacitor C.

$$C = \frac{Q}{V}$$

$$= \frac{9 \times 10^{-8}}{120}$$

capacitance = ... $7 \cdot 5 \times 10^{-10}$ ...... F [2]

(c) A second capacitor, having a capacitance equal to that of capacitor C, is now placed in series with C. combined capacitance decreases

Suggest and explain the effect on the current recorded on the ammeter.

Combined capacitance halves while V remains constant so current too halves.

....[2]

[Total: 9]

8 **(a)** Negative feedback is often used in amplifiers incorporating an operational amplifier (op-amp).

State

(i) what is meant by *negative feedback*,

Fraction of output is combined with the input

and it is deducted from input

....[2]

(ii) two effects of negative feedback on the gain of an amplifier.

1. increased bandwidth

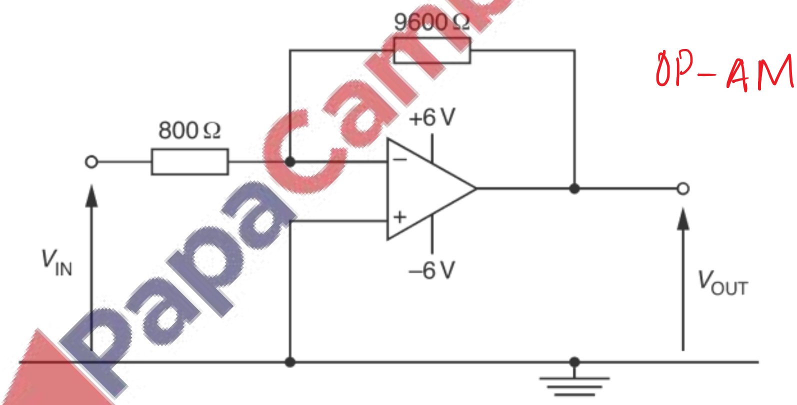
....

2. smaller gain

....

[2]

(b) An ideal op-amp is incorporated into the amplifier circuit shown in Fig. 8.1.



OP-AMP

Fig. 8.1

(i) Calculate the gain *G* of the amplifier circuit.

$$-I_{in} = I_{9600\Omega}$$

$$-\frac{V_{in}}{R_{in}} = \frac{V_{out}}{R_{9600}}$$

$$G = -\frac{R_{9600}}{R_{in}} = -\frac{9600}{800}$$

G = −12 [2]

(ii) Determine the output potential difference V_{OUT} for input potential differences V_{IN} of

1. −0.10 V,

$$V_{out} = -\frac{V_{in} \times 9600\,\Omega}{800}$$

V_{OUT} = 1.2 V

2. +1.3 V.

$$V_{out} = -\frac{1.3 \times 9600}{800}$$

$= -15.6\text{V}$ saturated so −6V

V_{OUT} = −6 V

[2]

(iii) The gain of the amplifier shown in Fig. 8.1 is constant.

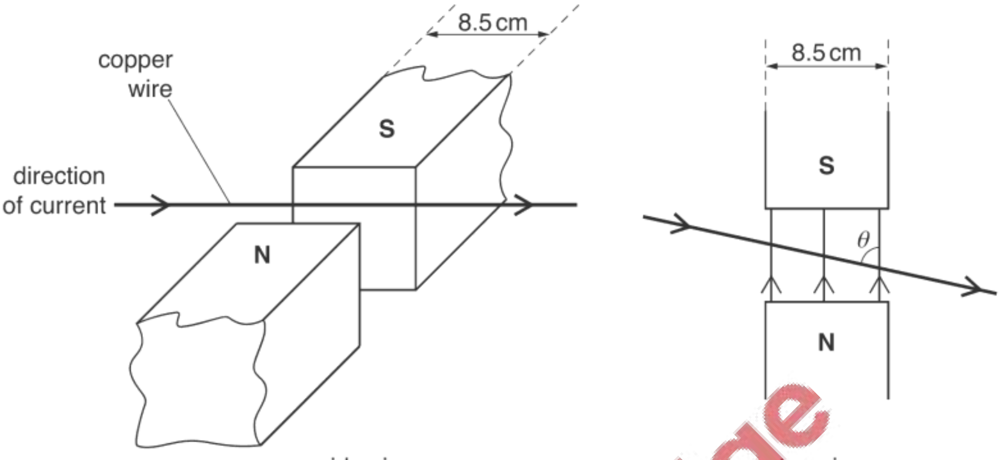
State one change that can be made to the circuit of Fig. 8.1 so that the amplifier circuit monitors light intensity levels, with the magnitude of the gain decreasing as light intensity increases. R_f or 9600Ω can change

Replace 9600Ω by LDR

[1]

[Total: 9]

9 A rigid copper wire is held horizontally between the pole pieces of two magnets, as shown in Fig. 9.1.



side view

top view

Fig. 9.1

The width of each pole piece is 8.5 cm.
The uniform magnetic flux density B in the region between the poles of the magnets is 3.7 mT and is zero outside this region.
The angle between the wire and the direction of the magnetic field is θ.
The current in the wire is in the direction shown on Fig. 9.1.

(a) By reference to the **side** view of Fig. 9.1, state and explain the direction of the force on the **magnets**.

Force on the wire is upwards according to Fleming's Left Hand rule and according to Newton's 3rd law, force on the magnets would be downwards.

.... [2]

(b) The constant current in the wire is 5.1 A.

(i) For angle θ equal to 90°, calculate the force on the wire.

$F = BIL$ → length of the wire in the region where flux density is uniform

$= 3.7 \times 10^{-3} \times 5.1 \times \frac{8.5}{100}$

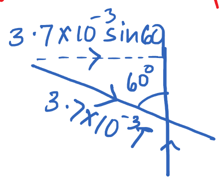
force = 1.6×10^{-3} N [2]

(ii) The angle θ is changed to 60°.

we need component of B which is at 90° to field lines

The length of wire in the magnetic field is $\left(\frac{8.5}{\sin 60°}\right)$ cm.

Calculate the force on the wire.



$$F = 3.7\times10^{-3}\sin 60° \times 5.1 \times \frac{8.5\times10^{-2}}{\sin 60°}$$

force = 1.6×10^{-3} .... N [1]

$I_A = \frac{I_{rms}}{0.707}$ $I_A = 7.21358\,A$ $T = 0.05\,s$

(c) The constant current in the wire is now changed to an alternating current of frequency 20 Hz and root-mean-square (r.m.s.) value 5.1 A. I_{rms} steady current that gives same avg. power as a.c.

The angle between the wire and the direction of the magnetic field is 90°.

On Fig. 9.2, sketch a graph to show the variation with time *t* of the force *F* on the wire for two cycles of the alternating current.

$F = BIL$

$= 3.7\times10^{-3} \times 7.2136 \times \frac{8.5}{100}$

$= 2.3\times10^{-3}$ N so peak force is this and $T = 0.05$ s

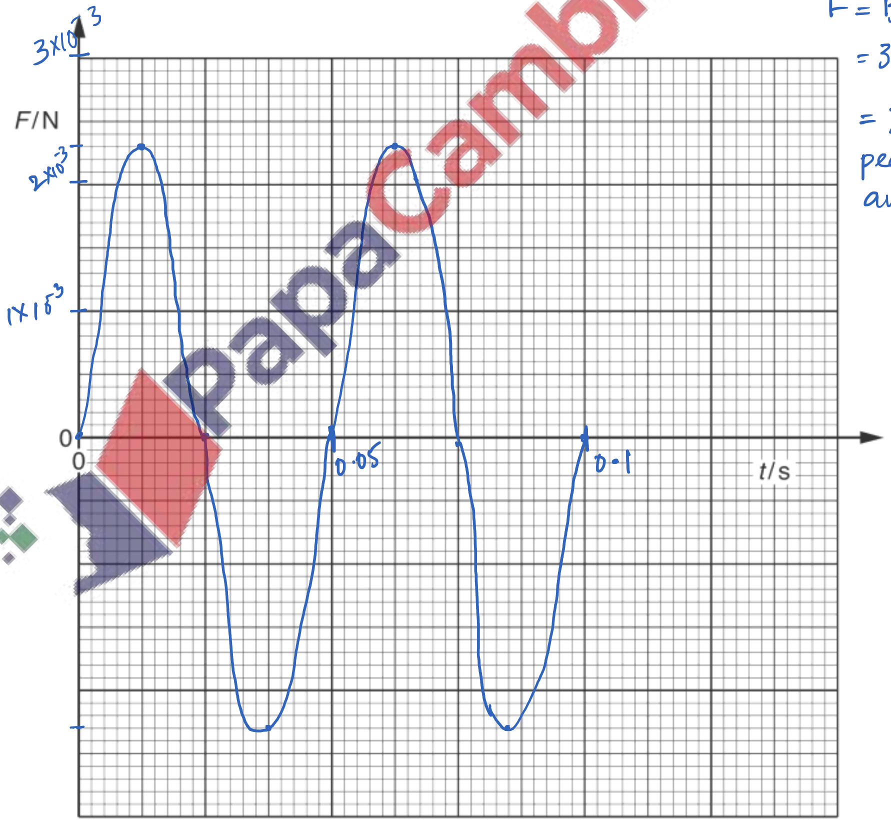


Fig. 9.2

[3]

[Total: 8]

10 **(a)** State Faraday's law of electromagnetic induction.

Induced emf is directly proportional to rate of change of magnetic flux linkage

[2]

(b) A coil of insulated wire is wound on to one end of a ferrous core and connected to a battery, as shown in Fig. 10.1.

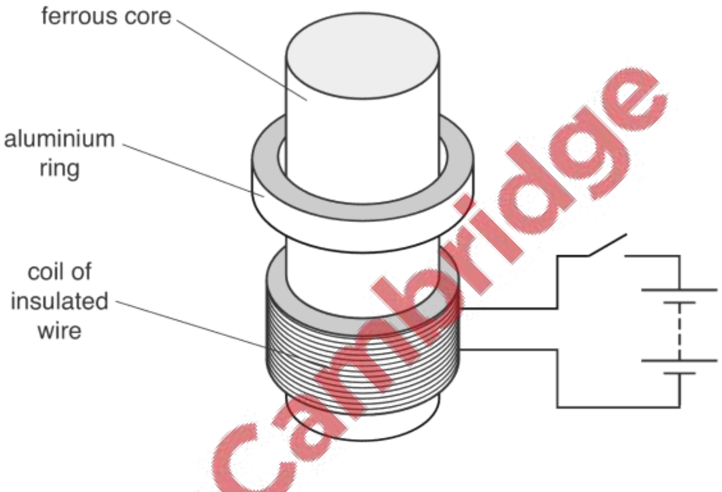


Fig. 10.1

An aluminium ring is placed on the core. The ring can move freely along the length of the core.

The switch is initially open.

Use Faraday's law and Lenz's law to explain why the aluminium ring jumps upwards when the switch is closed.

When the switch is closed, the current starts to flow in the coil which produces magnetic flux. The change in magnetic flux induces emf in aluminium ring too which means current is now flowing in the ring too and a field is created around the ring. According to lenz's law the field around the coil opposes the field around the ring which is why it is repelled and jumps

[4]

[Total: 6]

11 **(a)** **(i)** Explain what is meant by a *photon*.

Packet of energy of electromagnetic radiation

....[2]

(ii) By reference to intensity of light, state one piece of evidence provided by the photoelectric effect for a particulate nature of light.

Increasing intensity has no effect on energies of electrons

....[1]

(b) Some electron energy levels in a solid are illustrated in Fig. 11.1.

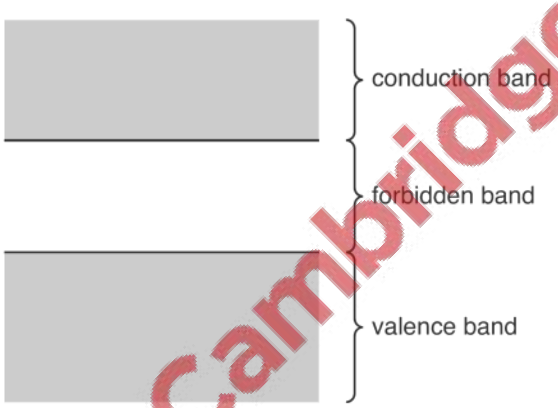


Fig. 11.1

A semiconductor material has a very high resistance in darkness.
Light incident on the semiconductor material causes its resistance to decrease.

Explain the resistance of the semiconductor material in different light conditions.

During darkness, conduction band is empty which is why high resistance. In daylight, electrons in valence band absorb photons and jump to conduction band leaving behind holes in valence band. This results in more charge carriers so resistance decreases.

....[5]

[Total: 8]

12 An X-ray beam is used to produce an image of a model of a thumb.
A parallel beam of X-ray radiation of intensity I_0 is incident on the model, as illustrated in Fig. 12.1.

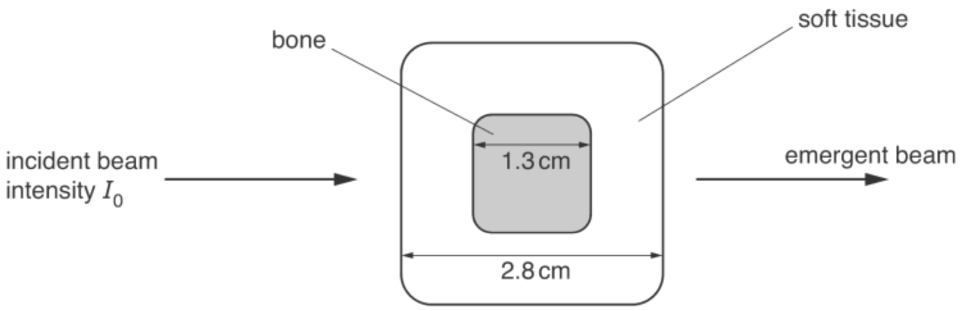


Fig. 12.1

Data for the attenuation (absorption) coefficient μ in bone and in soft tissue are shown in Fig. 12.2.

	μ / cm^{-1}
bone	3.0
soft tissue	0.90

Fig. 12.2

(a) Calculate, in terms of the incident intensity I_0 of the X-ray beam, the intensity of the beam after passing through

(i) a thickness of 2.8 cm of soft tissue,

Intensity at any instant $= I_0 e^{-\mu x}$

$= I_0 e^{-0.9(2.8)}$

intensity = ...0.08...... I_0 [2]

(ii) the bone and soft tissue, as shown in Fig. 12.1.

$$I = I_0 e^{(-0.9\times 2.8)\times(3\times 1.3)}$$

intensity = 0.0052 I_0 [2]

(b) **(i)** State what is meant by the *contrast* of an X-ray image.

about absorbers of X rays. If not absorbed, then black. If absorb well then they show up on photographic film

Difference in blackening degrees between structures

[2]

(ii) By reference to your answers in **(a)**, suggest whether the X-ray image of the model has good contrast.

The larger the difference between the intensities the better the contrast hence the model has good contrast

[1]

[Total: 7]

Tissues output intensity is 0.08 I_0 and on whole the output intensity is 0.0052 I_0 which suggests that the difference in observed intensities is large.

13 **(a)** State what is meant by *radioactive decay*.

Emission of particles by unstable nucleus which is also spontaneous .

[2]

(b) The variation with time t of the number N of technetium-101 nuclei in a sample of radioactive material is shown in Fig. 13.1.

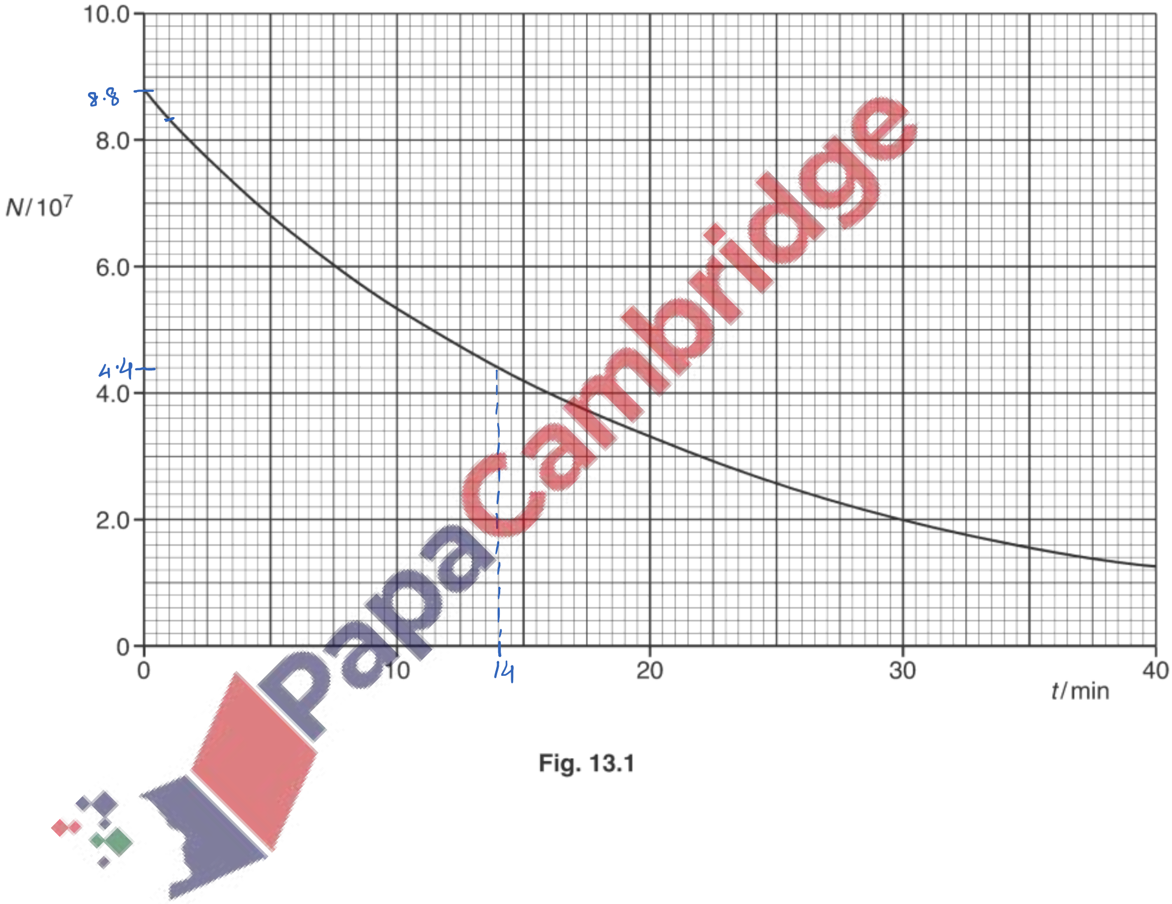


Fig. 13.1

(i) Use Fig. 13.1 to determine the activity, in Bq, of the sample of technetium-101 at time t = 14.0 minutes. Show your working.

$A = -\lambda N$ where N is no. of undecayed nuclei in the sample at that time and λ is decay constant

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{14 \times 60}$$

$$A = -\frac{\ln 2}{14 \times 60} \times 4.4 \times 10^{7}$$

activity = 3.6×10^{4} Bq [4]

(ii) Without calculating the half-life of technetium-101, use your answer in **(i)** to determine the decay constant λ of technetium-101.

$$A = -\lambda N$$

$$\frac{3.6 \times 10^{4}}{4.4 \times 10^{7}} = -\lambda$$

λ = 8.2×10^{-4} s^{-1} [2]

[Total: 8]

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